1 HKN nuclear parton distribution functions

Shunzo Kumano

KEK Theory Center, Institute of Particle and Nuclear Studies, KEK
and Department of Particle and Nuclear Studies, Graduate University for Advanced Studies
1-1, Ooho, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

Nuclear parton distribution functions determined by Hirai, Kumano, and Nagai (HKN) are explained. Their analysis method is introduced, and determined nuclear modifications are shown.

1.1 Analysis method

Nuclear parton distribution functions (NPDFs) are determined by a global analysis of world data on charged-lepton deep inelastic scattering and Drell-Yan processes with nuclear targets. First, the NPDFs are expressed in terms of a number of parameters which are determined by a χ^2 analysis. Since the PDFs of the nucleon are relatively well determined, it is appropriate to parametrize nuclear modifications from the nucleonic PDFs. The NPDFs are defined at the initial Q^2 scale ($\equiv Q_0^2 = 1$ GeV^2) as [1, 2]

$$f_i^A(x, Q_0^2) = w_i(x, A, Z) f_i(x, Q_0^2), \tag{1}$$

where $f_i^A(x, Q_0^2)$ is the parton distribution of the type i ($= u_v$, d_v, $\bar{u}$, $\bar{d}$, s, g) in a nucleus, $f_i(x, Q_0^2)$ is the corresponding parton distribution in the nucleon, A is the mass number, and Z is the atomic number. The function $w_i(x, A, Z)$ indicates a nuclear modification for the type-i distribution, and it is expressed as

$$w_i(x, A, Z) = 1 + \left(1 - \frac{1}{A^\alpha}\right) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}, \tag{2}$$

where α, a_i, b_i, c_i, d_i, and β_i are parameters to be determined by a χ^2 analysis. Here, the valence up- and down-quark parameters are the same except a_{u_v} and a_{d_v}. Since there is no data to find flavor dependence in antiquark modifications [3], the weight functions of $\bar{u}$, $\bar{d}$, and $\bar{s}$ are assumed to be the same at Q_0^2. We impose three constraints by baryon-number, charge, and momentum conservations, so that three parameters are fixed.

The initial NPDFs are evolved to experimental Q^2 points by the DGLAP equations. Using the evolved NPDFs, we calculate $F_2^A/F_2^{A'}$ and Drell-Yan ratios $\sigma_{DY}^A/\sigma_{DY}^{A'}$, and then the parameters are determined by minimizing χ^2.

1.2 Determined nuclear PDFs

Here, we explain the main results of the HKN07 analysis [2]. The used data consist of 290, 606, 293, and 52 data points for F_2^D/F_2^p, F_2^A/F_2^D, $F_2^A/F_2^{A'}$ ($A' \neq D$), and $\sigma_{DY}^A/\sigma_{DY}^{A'}$, respectively. For the total 1241 data, we obtained the minimum χ^2 values, χ^2_{min}/d.o.f.=1.35 and 1.21 for the leading order (LO) and next-to-leading order (NLO). Determined NPDFs are shown for the calcium nucleus in Fig. 1 at Q^2=1 GeV^2. LO and NLO results are shown with uncertainty bands for the nuclear modifications of u_v, $\bar{q}$, and g. The NPDFs are determined more accurately in the NLO because the uncertainty bands are generally smaller in NLO than those of LO.

The valence-quark modifications are well determined because of accurate measurements on the F_2 ratios at medium x. The small-x region is fixed by the baryon-number and charge conservations together with the modifications in the medium- and large-x regions.

The antiquark modifications are also determined well at small x due to measurements on F_2 shadowing, and they are also fixed at $x \sim 0.1$ because of Fermilab Drell-Yan measurements. However, the region at $x > 0.2$ is not determined at all. Right now, the experimental project is in progress by the E906/SeaQuest collaboration to measure this medium-x region. In the near future, the uncertainty bands should be significantly reduced for the antiquark. There is also a possibility to measure the region by a J-PARC experiment.

Gluon distributions have the large uncertainties. They contribute to the F_2 and Drell-Yan ratios as higher-order effects. It indicates that the gluon distributions cannot be accurately determined especially in the LO analysis. In the nucleonic PDFs, the gluon distribution is determined by scaling violation of F_2 measured at HERA. However, Q^2 dependence of $F_2^A/F_2^{A'}$ is not measured accurately, which makes it difficult to pin down the gluon modifications. The small-x NPDFs are dominated by huge gluon distributions, so that it is essential to determine them accurately for new discoveries by high-energy heavy-ion experiments. Therefore, it is important to measure Q^2 dependence of $F_2^A/F_2^{A'}$ at EIC for determining nuclear gluon distributions.

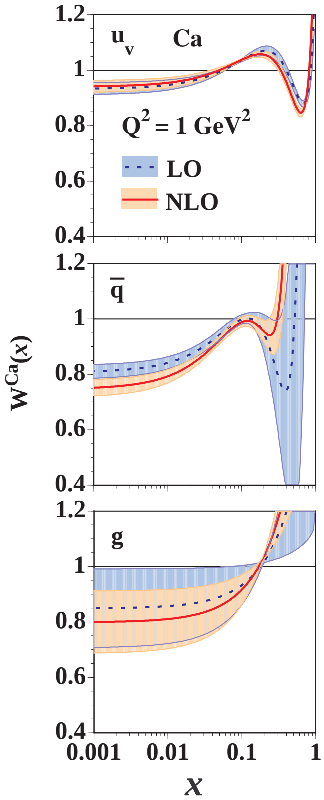

Figure 1: Determined nuclear modifications in Ca [2].

In the HKN07, the NPDFs are also investigated for the deuteron. In obtaining the "nucleonic" PDFs, deuteron data are used after crude nuclear corrections. Since the current PDFs could possibly contain nuclear effects, appropriate nuclear corrections should be applied in future for excluding such effects. Our codes for calculating the NPDFs and their uncertainties are available at the web site [4]. The technical details are explained in Refs. [1, 2] and within the subroutine.

References

[1] M. Hirai, S. Kumano and T. H. Nagai, Phys. Rev. C **70**, 044905 (2004) [arXiv:hep-ph/0404093]; M. Hirai, S. Kumano and M. Miyama, Phys. Rev. D **64**, 034003 (2001) [arXiv:hep-ph/0103208].

[2] M. Hirai, S. Kumano and T. H. Nagai, Phys. Rev. C **76**, 065207 (2007) [arXiv:0709.3038 [hep-ph]].

[3] S. Kumano, Phys. Rept. **303**, 183 (1998) [arXiv:hep-ph/9702367].

[4] The HKN-NPDF code is available at http://research.kek.jp/people/kumanos/nuclp.html.